RMB™ TECHNOLOGY DELIVERS PROVEN SINGLE DIGIT NOx & CO IN BOILERS & AIR HEATERS

by

Timothy Webster
Michael Brecker
TODD Combustion
A KOCH INDUSTRIES • JOHN ZINK COMPANY
Shelton, CT

Steve Bortz
Dale Shore
Radian International
Irvine, CA

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ABSTRACT

In the development of the Rapid Mix Burner (RMB^{TM}), NOx formation fundamentals were used to design a gas injection and mixing system radically different from all other commercially available low NOx burners. The goal was to produce a burner that was capable of reliable operation with single digit NOx firing gaseous fuels, such as natural gas. A new gas mixing approach was incorporated into an established burner geometry that had been optimized over the years at the International Flame Research Foundation to provide an extremely stable flame.

The resulting Rapid Mix Burner design has been proven to reliably produce single digit NOx, CO, and VOC emissions. Since 1994 the RMB has been successfully applied to over forty watertube boilers ranging in size from 25,000 to 230,000 lb/hr, as well as over a dozen fired air heater applications ranging from 1.5 to 118 MMBtu/hr. The RMB has been applied in both single burner and dual burner configurations, and both with and without the use of preheated combustion air. The wide variety of applications has shown the consistent ability of the RMB to reliably meet single digit emissions of NOx, CO, and VOC.

TECHNICAL BACKGROUND

Previous low NOx burner designs focused primarily on the reduction of NOx emissions through techniques to reduce the formation of thermal NOx. Techniques such as fuel-air staging, flue gas recirculation, and steam injection serve to lower NOx emissions into the 20 to 30 ppm range by lowering the peak flame temperatures. These methods do little to address the other mechanism for NOx formation, prompt NOx, and thus are not able to reliably reach single digit NOx levels. Because some of these techniques also rely on delaying combustion and lowering reaction temperatures, incomplete combustion has led to increased CO and VOC emissions.

In developing the RMB, the control of CO and VOC emissions in addition to NOx was targeted, and an Ultra Low Emissions Burner, as opposed to just an Ultra Low NOx Burner, was the result. In addition to reliably controlling NOx emissions below 9 ppm, CO emissions are also kept below 9 ppm, and VOC emissions are kept to less than 1 ppm.

The relationship between temperature, stoichiometry and NOx formation was used as the basis for design of the RMB. Thermal NOx emissions are the major source of NOx from these fuels, with NOx being created through the following high-temperature reactions of atmospheric nitrogen and oxygen from the combustion air:

$$N + O_2 = NO + O$$

$$N + OH = NO + H$$

$$N_2 + O = NO + N$$

Thermal NOx formation can be reduced through control of peak flame temperature. While thermal NOx is dependent to some extent on oxygen availability, if the temperature can be lowered sufficiently, thermal NOx emissions from a natural gas flame can be reduced to less than 1 ppm. Figure 1 shows the relationship between the adiabatic flame temperature and thermal NOx formation.

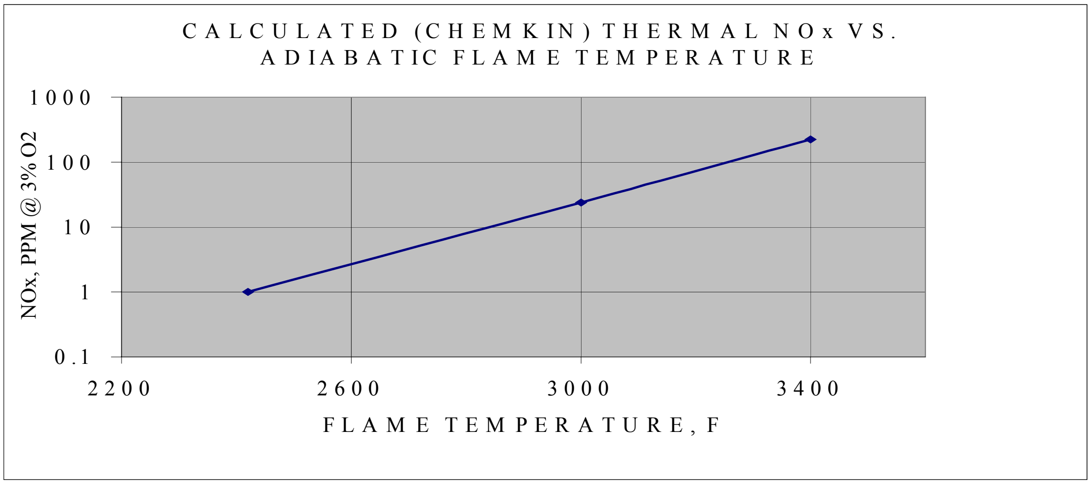

Figure 1

In attaining ultra low NOx levels, prompt NOx also becomes a significant emissions source. Under fuel-rich conditions, particularly when stoichiometry is under 0.6, both HCN and NH_3 can be formed through the extremely rapid reaction of CH with N_2 to form HCN and N. As combustion continues the HCN and NH_3 act just like fuels containing nitrogen, and they result in the generation of NOx. The following reactions are considered:

$$CH + N_2 = HCN + N$$

$$N + H_2 = NH + H$$

$$NH + H_2 = NH_3$$

$$HCN + O_2 = NO + HCO$$

Below a stoichiometry of 0.5, almost all NOx formed is attributable to prompt NOx. The rate of formation of prompt NOx is very rapid, being complete in under 1 ms. Although prompt NOx is temperature-sensitive, the temperature sensitivity is not as great as with thermal NOx. Unlike thermal NOx, simply lowering the peak flame temperatures will not reduce the prompt NOx into the single digit range. Even if the reaction temperature is lowered to 2,400^{o} F, under fuel-rich conditions, 20 ppm of prompt NOx still remains. In order to control the formation of prompt NOx it is necessary to take steps in the burner design to minimize the formation of sub-stoichiometric regions within the flame.

RAPID MIX BURNER THEORY

Most conventional low NOx burners utilize staged combustion to delay the mixing of fuel and air. By creating an initial fuel-rich combustion zone and adding air downstream to complete combustion, oxygen availability is limited, peak flame temperature is lowered, and thermal NOx formation is reduced. It can be further reduced through other techniques, such as the addition of flue gas recirculation (FGR) or steam injection. However, the 20 ppm of prompt NOx created in the initial fuel-rich zone remains. It is this prompt NOx formation that has prevented conventional low NOx burners from achieving sub-9 ppm NOx levels.

By "starting over" with NOx formation fundamentals, it was determined that the most direct method of achieving very low NOx emissions from a natural gas flame is to: 1) avoid fuel-rich regions with their corresponding potential for prompt NOx, and 2) lower the flame temperature to reduce thermal NOx to the desired level. To accomplish this a burner design that avoids fuel-rich regions by rapidly mixing gaseous fuel and air near the burner exit was developed. The rapid mixing results in a nearly uniform fuel/air mixture at the ignition point, which virtually eliminates prompt NOx formation. This rapid and complete combustion is also what results in the virtual elimination of both CO and VOC formation by the burner. Thermal NOx is then minimized by using FGR, which is mixed with combustion air upstream of the burner, to control flame temperature. In effect, the burner performs like a pre-mix burner with one important distinction: because the fuel is added inside the burner, just upstream of the refractory throat, the extremely small pre-mixed volume eliminates the possibility of flashback inherent in pre-mix burner designs.

Contrary to conventional low NOx burner theory, increasing excess air *reduces* NOx formation in the Rapid Mix Burner. Because the burner employs near perfect mixing, the fuel already has access to all of the oxygen required at the ignition point, and increasing excess air just serves to reduce the peak flame temperatures. Therefore, excess air has the same cooling effect as FGR, which provides major advantages in high excess-air combustion applications, such as dryers, where FGR is impractical or unavailable. In boiler applications, where FGR is available, it is preferred due to its lower impact on the boiler efficiency than high excess air. The rapid mix design is also what allows the burner to operate with pre-heated combustion for increased efficiency, and still retain its single digit emissions performance, by simply increasing the FGR or excess air rates to compensate for the higher air temperature.

RAPID MIX BURNER DESIGN

The basic Rapid Mix Burner consists of a parallel-flow air register with no moving parts. Combustion air pre-mixed with FGR enters the register, and the entire mixture then passes through a set of axial swirl vanes. These vanes, which are attached to a central gas reservoir, have hollow bases that are perforated for gas injection. Thus, the swirl vanes also serve as the gas injectors, and provide the burner's near perfect fuel/air mixing (Figure 2).

For burner heat inputs greater than about 40 MMBtu/hr, a second parallel-flow air sleeve surrounds the basic burner register, and the burner is called a Dual Rapid Mix Burner (DRMB^{TM}). The outer sleeve contains a second set of gas injector vanes attached to an outer gas reservoir. These vanes, however, do not impart any swirl to the airflow. Airflow through the inner and outer burners is designated as "primary" and "secondary" airflow, respectively. Both the primary/swirled and secondary/axial zones operate with the same, near perfect mixing.

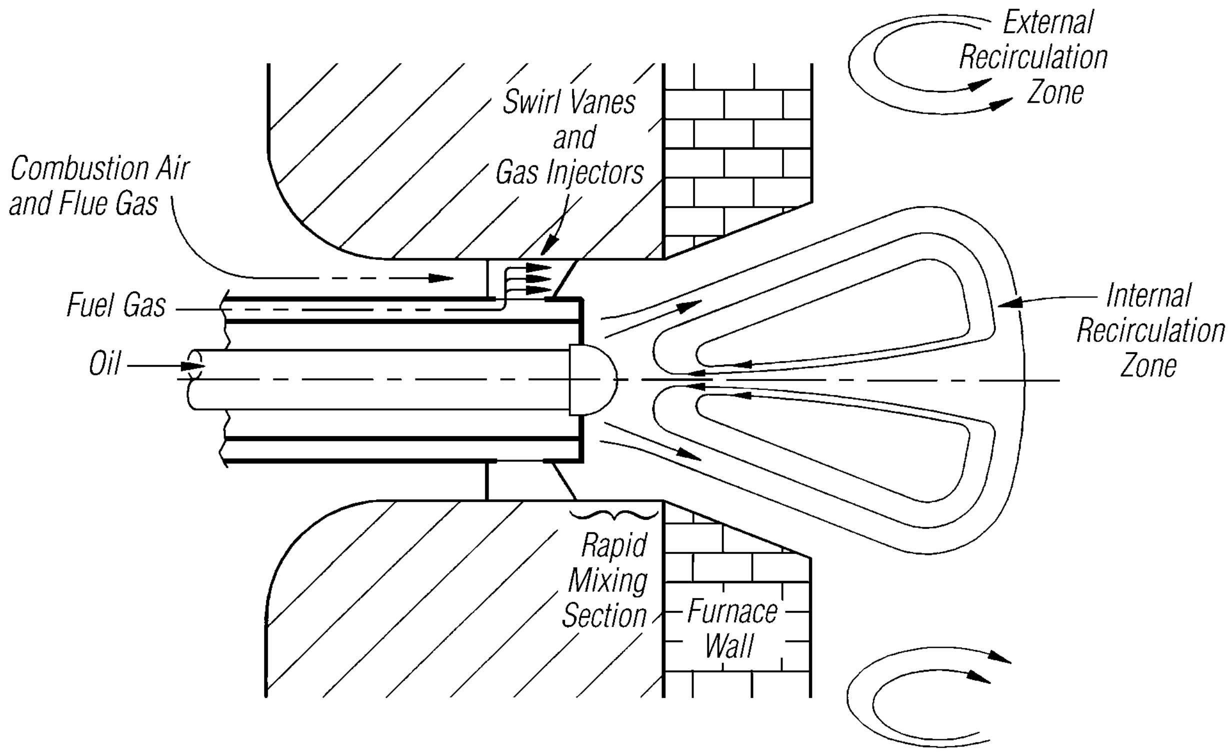

Figure 2

In addition to sub-9 ppm NOx and CO, another benefit of the rapid mix design is an extremely stable flame. Swirler geometry, burner internal geometry and quarl expansion are matched to promote internal recirculation of a large amount of hot combustion gases. This enables the burner to operate at lower flame temperatures and NOx levels than other burners, with a "blow off" point of about 3 ppm NOx. The RMB flame remains stable at 60% FGR, therefore the 25-30% FGR rate typically necessary for sub-9 ppm NOx does not begin to approach the burner's performance limits. The rapid combustion also results in a very short flame length. It is approximately half that of a staged-combustion burner, which eliminates the potential for flame impingement, one of the most common problems experienced with conventional low NOx burner retrofits.

For oil firing, the Ultra Low Emissions Burner uses a conventional center-mounted atomizer gun assembly. The burner operates as a conventional, staged-combustion low NOx burner when firing oil. While there is no rapid mixing, fuel staging is provided by advanced atomizer designs, and air staging is provided by the burners primary and secondary airflows. This allows emissions performance on oil firing equivalent to any other low NOx burner available.

RAPID MIX BURNER DEVELOPMENT

The development program for the RMB, consisted of testing in a 4 MMBtu/hr firetube boiler, a 30 MMBtu/hr watertube boiler, and a 100 MMBtu/hr test facility, and was conducted from mid-1993 to mid-1994. Air preheat was available on both the firetube boiler and large test facility furnace, but not on the watertube boiler.

NOx emission from the RMB firing into the firetube boiler for ambient, 300°F preheat and 500°F preheat as a function of FGR rate are shown in Figure 3.

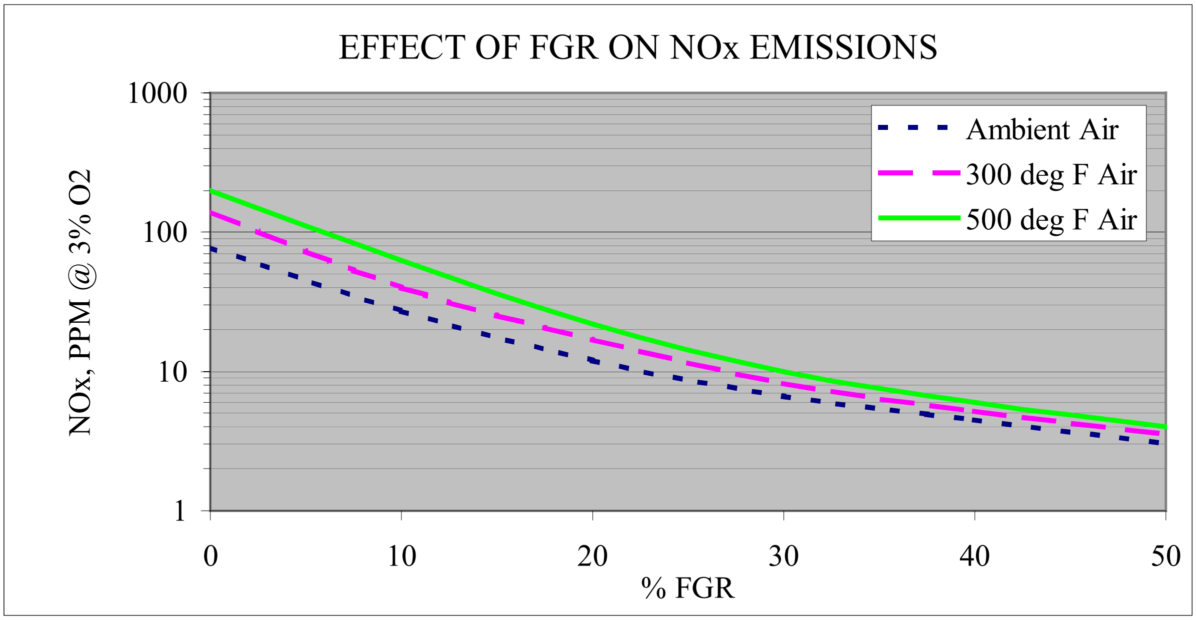

Figure 3

NOx emissions without FGR were a function of air preheat level and ranged from approximately 80 ppm with ambient air to 200 ppm with 500°F preheat. The FGR rate required to produce a given NOx emission level varied with air preheat level, but, independent of the preheat level, NOx emissions could be reduced to approximately 3 ppm.

Similar results were obtained in the 25,000 lb/hr watertube boiler (30 MMBtu/hr). The NOx emissions without FGR were higher for the larger burner, but when enough FGR was added to reduce NOx below 20 ppm, both size burners exhibited very similar performance. Similar characteristics were also observed with air preheat on the 100 MMBtu/hr test furnace. Again, the larger burner produces higher NOx emissions without FGR, but once FGR is added, the NOx emissions from the 4 MMBtu/hr and 100 MMBtu/hr burners are almost identical for a given FGR rate.

COMMERCIAL INSTALLATIONS

Since 1994 the Rapid Mix Burner has been supplied for use on over thirty-five packaged boilers, ranging from 25,000 to 230,000 lb/hr, and on five field-erected boilers ranging from 85,000 to 100,000 lb/hr. In addition to boiler applications, the RMB has been used on seventeen direct fired air heaters, with heat inputs ranging from 1.5 to 118 MMBtu/hr, and several thermal oil heaters. Figure 4 shows the boiler capacity distribution of the RMB's that have been supplied.

RMB Burners on Package Boilers

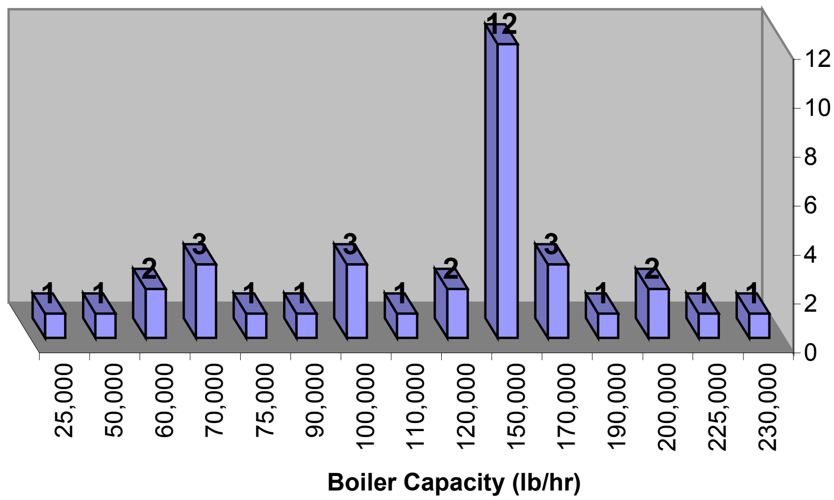

Figure 4

Currently, RMB design heat inputs range from 5 million to 300 million Btu/hr for a single burner, and for units requiring higher heat inputs two RMB burners can be fired in unison. Operating requirements include fuel gas supply pressure at the burner of only 8 psig and a windbox-to-furnace pressure differential of 8" w.c. Excess O_2 is typically between 3% and 4% at full load, but may be slightly higher at the lower loads. Flue gas flow rates of 25-30% are typically required to reach the sub-9 ppm NOx level, or the use of 50-60% excess air can be substituted in place of FGR. Table 1 shows actual source testing data from three different size units, and confirms the RMB's ability to easily meet the single digit emissions requirements across the operating range.

Source Test Data from 25,000 lb/hr boiler			
Load (%)	O2 (%)	NOx (ppm)	CO (ppm)
25	3.4	8.2	3.0
53	2.6	7.1	0.9
98	2.7	6.8	0.1
Source Test Data from 100,000 lb/hr boiler			
Load (%)	O2 (%)	NOx (ppm)	CO (ppm)
29	3.4	8.7	<1
55	3.4	7.6	<1
100	3.2	8.7	<1
Source Test Data from 130,000 lb/hr boiler			
Load (%)	O2 (%)	NOx (ppm)	CO (ppm)
25	3.4	8.1	<1
50	3.4	8.2	<1
100	3.2	8.3	<1

Table 1

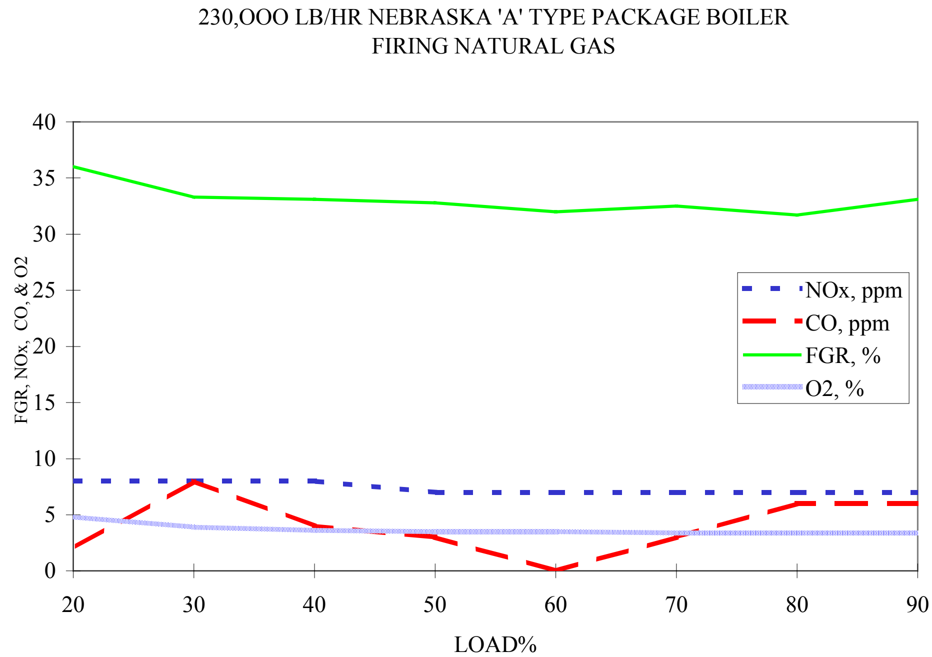

Figure 5

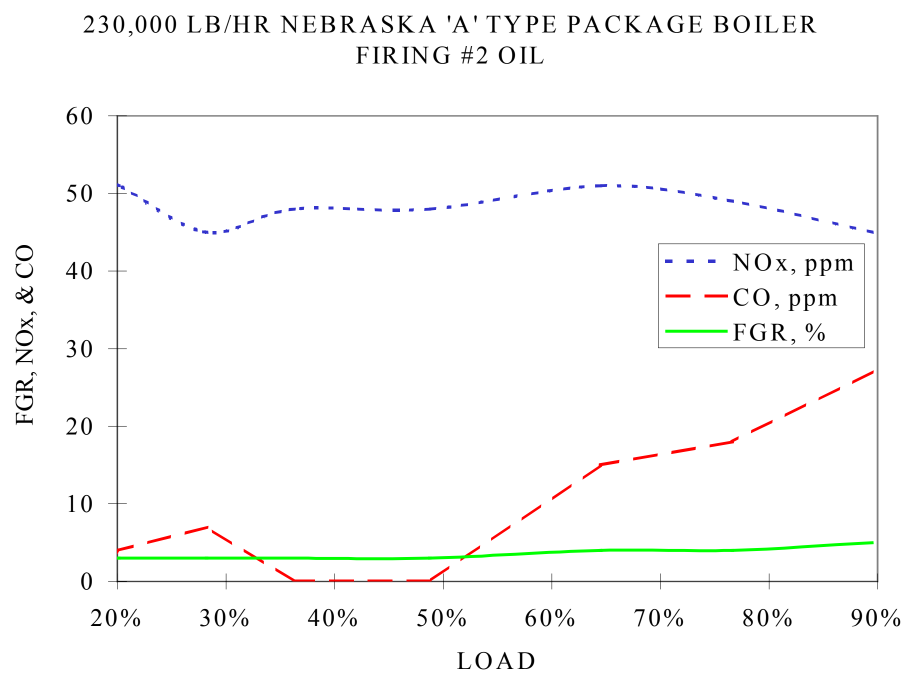

Figure 6

Figures 5 & 6 shows actual data taken from the testing of a DRMB burner supplied for a 230,000 Nebraska "A" type package boiler, and shows the burners ability to operate on liquid fuels, such as #2 oil, in addition to gaseous fuels. This unit is one of seven boilers that are operated with a Continuous

Emissions Monitor (CEM) and has provided consistent emissions performance since it was put into operation almost three years ago. The other units range in size from 70,000 lb/hr to 100,000 lb/hr and have all provided years of reliable performance.

The RMB burner has also been applied in dual-burner applications on both field erected and packaged boilers. In 1997 an extensive demonstration project was undertaken at utility site in conjunction with the Electric Power Research Institute. A 150,000 lb/hr 'D' type packaged boiler with two existing register burners was retrofitted with two DRMB's. Each burner was rated for 88 MMBtu/hr, and the unit was operated with a combustion air pre-heat temperature of 500 °F. To minimize the amount of FGR required, staging between the two burners was employed to reduce NOx. Even with the high air pre-heat, the burners were able to reduce the NOx to single digit levels with only 25% FGR and CO was maintained at less than 5 ppm. The dual-burner configuration has been successfully applied to five other boilers, both with ambient and pre-heated combustion air.

In order to provide optimum performance in terms of reliability and emissions it is necessary to ensure that proper excess air levels are maintained both during steady state operation and during load changes. Both single-point positioning and fully metered control systems have been designed and successfully implemented for use with the RMB. A ramp time from minimum to maximum firing rate of three minutes, which corresponds to most boiler manufacturers maximum recommended ramping rate, can be achieved by either of these control schemes. A burner turndown ratio of 6:1, or better, can be achieved on gas firing with ambient combustion air. The use of fast-reacting flame scanners, with Flame Failure Response Times (FFRT) of one second or less, are also supplied as part of every RMB Burner Management System (BMS). This added feature ensures optimum safety by shutting down the fuel supply to the burner immediately upon the loss of a stable flame.

SUMMARY

The RMB has demonstrated its superiority in demanding ultra-low emissions applications with continuous safe operation. Heat inputs from 1.5 to 272 million Btu/hr have been demonstrated and boilers with CEMS have been operated with successful results over the entire turndown range. Repeatable performance of this technology has been demonstrated across a wide range of applications and sizes, and single digit emissions performance has been consistently achieved. The operational performance of the burner has shown that Rapid Mix Burner Technology is a proven reliable alternative to the control of combustion emissions through the use of flue gas cleaning technologies, such as SCR or SNCR. In addition the use of an Ultra Low Emissions Burner can be accomplished at much lower capitol installation costs, lower annual operating costs, and without the added complication of ammonia handling and emissions.